Development of a hybrid vibration experiment system for determining wind-induced responses of buildings with tuned dampers

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ABSTRACT: The aim of this study was to develop a hybrid vibration experiment system that can evaluate the performance of complicated vibration dampers, e.g. sloshing dampers, which show high nonlinearity. To this end, a system consisting of a computer and an actuator was developed, and applied to an experiment on a building with a tuned mass damper under wind load. The system’s accuracy and effectiveness was thus confirmed.

KEYWORDS: Hybrid vibration experiment, Tuned mass damper, Wind-induced response

1. INTRODUCTION
Techniques for simulating physical phenomena include numerical computation, model experiments, and hybrid techniques incorporating both methods. A hybrid technique was proposed by Hakuno (1968), and has been applied in various fields. In the wind engineering field, it has been applied to wind tunnel experiments by Kanda (1994, 1995). In this study, the hybrid experiment technique is applied to wind affected structures equipped with complicated vibration damping devices. It is easy to carry out numerical modeling of tuned mass dampers consisting of simple mass and spring elements. However, because of the nonlinear nature of fluid, it is comparatively difficult to predict the characteristics of tuned liquid dampers that employ sloshing of liquid at the time of large amplitude and their action at the time of random vibration. This study was aimed at development of a hybrid vibration experiment system for evaluating such dampers.

2. EXPERIMENTAL SETUP
Figure 1 shows the experiment object, which consists of a building with a damper. The building motion excited by wind is simulated by a numerical model in a computer, where it is called virtual space. The damper, set at the top of the building, is simulated by a physical model.

Figure 2 shows the outline of the experimental

Figure 1 Building with damper
system. The driver installed in the computer orders the actuator to produce the building motion where the damper is set. This motion excites the damper through the shaking table. The damper's reaction force is measured by a load cell installed under the table. The load cell signal is transferred to the computer through the analog/digital converter installed in the computer. According to the measured damper reaction force and the wind force data stored in the computer, stepwise calculation is conducted for the response of the building and displacement of the actuator in the next step is evaluated. Along with this evaluation, the driver orders the motion of the actuator. These steps are repeated at constant intervals.

3. EXPERIMENTAL CONDITION

The properties of the target building and a damper are shown in Table 1. The building is 200m tall and 40m wide, and the generalized mass of the fundamental mode is determined by assuming that its density is 200 kg/m³ and its mode shape is linear. The building’s damping factor is determined from the recommendation for safety design in the literature 5). The natural period is determined from the empirical relation with the building height.

A damper is modeled as a single-degree-of-freedom (SDOF) system with a simple mass supported by two columns. Viscoelastic material is put among the mass and the shaking table. The aim of this system is to evaluate tuned dampers such as sloshing-type dampers whose properties are nonlinear and complicated. As the first stage of this research, a simple SDOF system is selected for a tuned damper, because of ease of confirmation, and this is followed by numerical calculations. The values of experimental scalings are 1/10 for length, $7.26 \times 10^{-2}$ for time and 1/1000 for mass. In the following experiments, response variation will be examined for several different conditions of natural frequency and damping factor of the building. A displacement meter and an accelerometer were set on the shaking table to verify the reproducibility of the actuator and the overall system.

Table 1 Properties of experiment and calculation

<table>
<thead>
<tr>
<th>Item</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generalized mass of building</td>
<td>$2.13 \times 10^7$ kg</td>
</tr>
<tr>
<td>Natural period of building</td>
<td>basically 3.8s, 30% changed</td>
</tr>
<tr>
<td>Damping factor of building</td>
<td>basically 0.02, changed among 0.01 and 0.2</td>
</tr>
<tr>
<td>Size of building</td>
<td>Breadth: Depth: Height=40m:40m:200m</td>
</tr>
<tr>
<td>Mass of damper</td>
<td>1% of generalized mass of building</td>
</tr>
<tr>
<td>Natural period and damping factor of damper</td>
<td>same as building period 3.8 s, 0.025</td>
</tr>
</tbody>
</table>
4. RESULTS AND DISCUSSION

4.1 Reproducibility of system

Examples of displacement and acceleration responses at the shaking table are shown in Figs. 3 (a) and (b). The system calculation results and the corresponding displacement meter and accelerometer measurements are almost identical, showing that the system is operating adequately.

4.2 Response variation with changes in building damping factor

Figure 4 shows the relation between the building’s damping factor and the response at the top of the building. The response is expressed as the root mean square (r.m.s.) value of the acceleration at the top of the building. The ratio of the natural period of the building is constant for these cases.

As the damping factor increases, the response and the damper’s efficiency both decrease. Calculations in which the damper is assumed as a SDOF system agree with the experimental results.

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Figure 4 Relation between the building’s damping factor and the response at the top of the building

Figure 5 Relation between the building’s natural period and the response at the top of the building (Calculated with evaluated parameters in every case)
4.3 Response variation with changes in building natural frequency

Figure 5 shows the relation between the building’s natural period and the response at the top of the building. The building’s natural period is normalized by the damper’s natural period. Thus, the abscissa indicates the damper’s tuning ratio. The building’s damping factor is constant: 0.02 for these cases. Even in a simple mechanical model, weak nonlinear properties may exist. Natural frequency and damping factor for every case in the experiment were identified using curve fitting of the SDOF transfer function. According to the damper’s response, the natural period and damping factor are slightly changed. Using these properties for calculations, the results were compared in Fig. 5. Calculations and experimental results show good agreement each other. Thus, the hybrid vibration experimental system can evaluate the modeled tuned mass damper appropriately.

5. CONCLUDING REMARKS

This study was aimed at development of a hybrid vibration experiment system that can evaluate complicated vibration dampers, e.g. sloshing dampers, that shows high nonlinearity.

A system consisting of a computer and an actuator was developed that can synchronize in real-time. This system was applied to an experiment on a building with a tuned mass damper under wind load. It was confirmed that the system worked accurately and effectively.

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REFERENCES